TOWARD THE USE OF PHASE CHANGE MATERIALS (PCM) IN CONCRETE PAVEMENTS: EVALUATION OF THERMAL PROPERTIES OF PCM

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INTRODUCTION

Phase change materials (PCM) have the potential to be used to store thermal energy from ambient, solar or applied sources. PCMs have been conventionally used in solar water-heating systems, green houses, building walls and floors, and even window shutters [1]–[3]. PCM may also be used in the concrete infrastructure to alter anti-icing practices in concrete pavements [4]–[7]. Due to the PCM's high heat of fusion, the stored energy can be released during cooling (i.e., during a freezing/icing event), thereby delaying or preventing ice formation. This can help to eliminate or decrease the deicing salt demand to melt ice or snow on the surface of concrete pavements. Deicing salts can cause premature deteriorations in concrete pavement by physical or chemical damage [8], [9]. Figure 1 shows schematic of using PCM in concrete pavement to melt ice and snow using a lightweight aggregate (LWA) [4], [6].
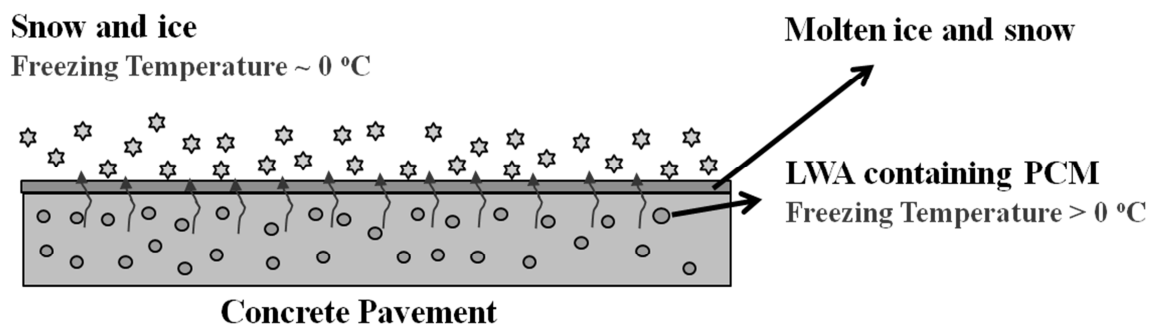

Figure 1. Schematic of using PCM in concrete pavement to melt ice and snow.

Using PCMs in the concrete infrastructure requires specific thermodynamic, physical, and chemical properties that are compatible with the concrete. The desirable thermal properties needed for successful use in concrete to melt ice include a phase transition temperature near 0 °C, high latent heat of fusion, high specific heat (heat capacity), and high thermal conductivity [4]–[7]. The PCM's physical properties should include high density, small volume change between phases, and low vapor pressure. PCM's chemical properties should include stability, compatibility with concrete, non-toxic, and non-flammable. PCMs that are economical, commercially available and environmentally friendly are also important.

Further, the PCMs should be able to be added to the concrete without extensive changes to the construction practice. Different methods have been proposed to use PCM in concrete elements [6], [10], [11]. Figure 2 illustrates schematics of three methods of incorporating a PCM into concrete. Figure 2a indicates filling steel tubes with liquid paraffin wax to raise the latent heat of the concrete-steel tube system, thereby preventing freezing of bridge layers. Figure 2b illustrates incorporating the PCM directly within LWA in the concrete slab [6]. Figure 2c depicts the inclusion of PCM within the concrete pores and voids on the surface of the pavement; this method has also been used for applying sealants to pavement surface [12]. The second two methods are likely simpler.

Sakulich and Bentz [4], [5] used different types of PCM in concrete and developed a finite difference model to simulate PCM concrete response in different locations of United State. They

reported that in 104 out of 237 locations, the use of PCM/ LWA composites shows promise in reducing freeze/thaw damage and a conservative dose of 50 kg/m^3 of PCM would increase concrete service life by at least one year. They also observed a reduction in compressive strength. Lower thermal diffusivity for PCM, increasing the dosage of PCM in concrete, increasing latent heat of the PCM, selecting a PCM with a melting temperature within the optimal range (3.55 and 6 °C) were found to decrease the length and/or depth of freezing events and to increase melting more ice and snow.
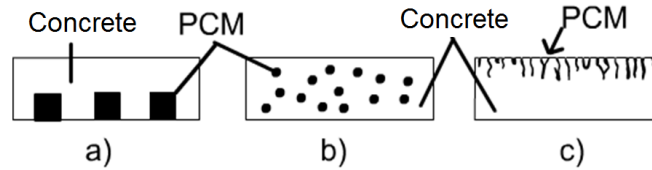

Figure 2. Schematic illustrating three methods to incorporate PCM into concrete: a) using pipes of PCM, b) using particles containing PCM, and c) filling concrete surface voids with PCM absorption.

In order to prove practical advantages of PCM incorporation in concrete pavement, more work is needed, especially in 1) optimizing thermal properties of PCM, 2) optimizing ways that PCM incorporation can be maximized in concrete, 3) investigating the composite thermal behavior of concrete possessing PCM, 4) evaluating changes in mechanical property, 5) understanding long-term behavior, and 6) studying PCM use in real pavement systems. Accordingly, the research team, as a part of a FAA study through the PEGASAS center, has begun to investigate the potential use of phase change materials (PCM) in concrete pavements to reduce ice formation and snow accumulation on concrete pavements. As a first step, it has been attempted in this paper to evaluate thermal properties of different PCMs made of fatty acids and methyl esters. The temperature of the liquid-solid phase transition is determined and the latent heat absorbed or released during the phase change is measured using a low temperature differential scanning calorimeter (LT-DSC) for each PCM. This work begins to discuss how the thermal properties can be changed by altering the compositions in order to remain in the desired temperature range. Additionally, this paper discusses how the use of PCM in concrete can be increased by changing absorption technique or LWA type.

MATERIALS AND COMPOSITION

Through transesterification, the methyl esters used in this work were derived from high oleic soybean oil, canola oil and corn oil. Figure 3 indicates the transesterification process. Triacylglycerides (TAG) are mixed with methanol and then catalytically converted into glycerol and fatty acid methyl esters (FAME). FAMEs have lower melting points than both TAGs and fatty acids from which they were derived. Unsaturated FAMEs (double bonds in the hydrocarbon chain) have lower melting points and less dense crystal structure than saturated FAMEs with the same number of carbons in the hydrocarbon chain [13], [14]. The properties of each pure methyl ester is indicated in Table 1. Unsaturated FAMEs form less dense crystal structures because the double bonds found in the hydrocarbon chain can prevent simple compact stacking between molecules. The terminal carboxylate at the end of the FAME molecule significantly changes their physical, chemical, and biological properties versus analogous length petroleum

hydrocarbons [15]. Most importantly, this carboxylate strengthens the intramolecular forces between the FAME molecules lowering vapor pressure and making them more chemically stable.
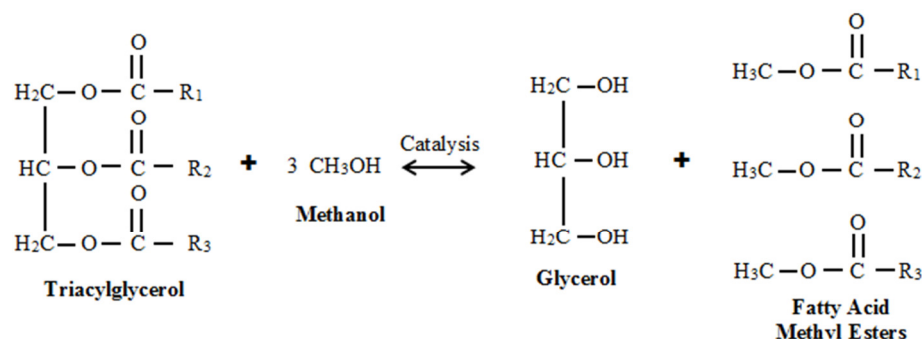

Figure 3. Transesterification process.

Table 1.
Individual pure methyl esters derived by transesterification and their thermal properties [16], [17].

Methyl Esters	Molecular Formula	Enthalpy of Fusion (J/g)	Melting Point (°C)
Methyl Palmitate (C16:0)[a]	$C_{17}H_{34}O_2$	222	29.6
Methyl Palmitoleate (C16:1)	$C_{17}H_{32}O_2$	-	-33.7
Methyl Stearate (C18:0)	$C_{19}H_{38}O_2$	237	38.7
Methyl Oleate (C18:1)	$C_{19}H_{36}O_2$	133	-19.4
Methyl Linoleate (C18:2)	$C_{19}H_{34}O_2$	121	-36.6
Methyl Linolenate (C18:3)	$C_{19}H_{32}O_2$	-	-49.0
Methyl Arachidate (C20:0)	$C_{21}H_{42}O_2$	-	46.4
Methyl Gadoleate (C20:1)	$C_{21}H_{40}O_2$	-	-34.0
Methyl Behenate (C22:0)	$C_{23}H_{46}O_2$	-	53.3
Methyl Erucate (C22:1)	$C_{23}H_{44}O_2$	-	-1.1

[a](C##:#): The first number represents the number of carbons in the hydrocarbon chain and the number after the colon represents the number of double bonds in the chain (the unsaturated methyl esters). The enthalpy of fusion is not available for all methyl esters.

High oleic soybean oil, canola oil, and corn oil were used to derive methyl esters (methoxylated long chain fatty acids). The compositions of high oleic soybean methyl esters, canola methyl esters, corn methyl esters, and generated methyl esters mixtures were determined using a Thermo Scientific TRACE™ Ultra Gas Chromatograph (GC) equipped with a variable split flow programmable temperature vaporizing injector (PTV), temperature programmable oven and a flame ionization detector (FID). The GC operating conditions were configured to follow the standard method, EN 14103-2011 [18]. The analytical capillary column used is a polar EC-WAX, 30 m length × 0.25 mm inner diameter × 0.25 μm film thickness and 1 μL of the sample diluted in hexane was injected with a carrier gas (helium) of 1.4ml/min. The PTV injector was at 250 °C with a split flow of 70 ml/min of helium (50:1 ratio). The oven programmed initial to start at 110 °C held for 0.5 min, a ramp of 20 °C/min to 130 °C held for

0.5 min, a ramp of 30 °C/min to 220 °C held for 1min, and ramp of 10 °C/min to 250 °C held for 7 minutes. The FID detector set at 275 °C with air flow of 300 ml/min, hydrogen of 30 ml/min and make-up flow (He) 30 ml/min.

A potential PCM with desired thermal properties can be obtained by combining different mixtures of fatty acids, methyl esters, and TAGs in order to be used in concrete pavement. Samples with different amounts of individual methyl esters (Table 1) were prepared to obtain a PCM with desired thermal properties. The compositions of all samples studied so far in this work summarized in Table 2 and Figure 4.

Figure 4. Summary of compositions of methyl esters.
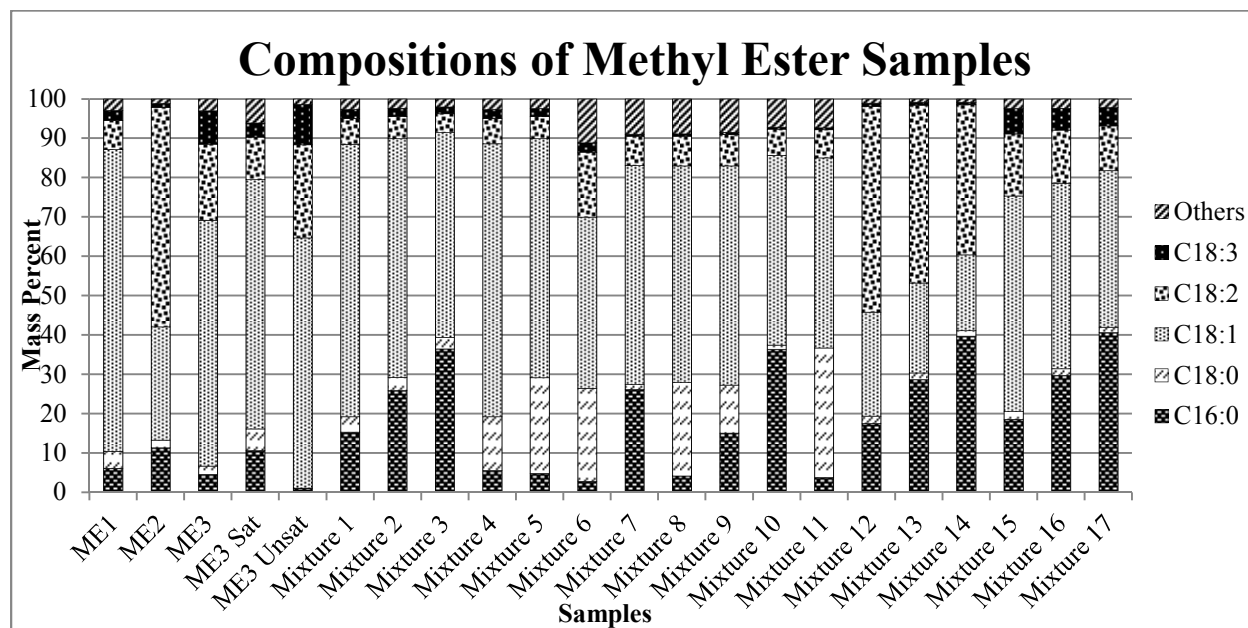
Two types of lightweight aggregate (LWA) were used in this study. The total theoretical capacity of PCM absorbing into LWA is important for determining the total amount of ice that can be melted. LWA #1 (Buildex Marquette) and LWA #2 (Haydite AX) were the two types of LWA used; these are common LWA used in Midwest. The properties of these LWAs are well described in [19].

Table 2.
Composition of methyl ester samples (mass percent).

Samples[a]	C16:0	C18:0	C18:1	C18:2	C18:3	Other[b]	Total Saturates[c]
ME1	6.1	4.3	76.8	7.4	2.5	3.0	11.4
ME2	11.3	1.9	28.8	55.8	0.9	1.2	14.1
ME3	4.5	2.1	62.4	19.4	8.4	3.1	7.8
ME3 Sat	10.5	5.6	63.3	10.8	3.5	6.2	19.2
ME3 Unsat	1.0	0.1	63.6	23.7	10.3	1.4	1.0
Mixture 1	15.3	3.9	69.3	6.6	2.3	2.7	20.1
Mixture 2	25.8	3.4	60.6	5.8	2.0	2.4	30.0
Mixture 3	36.4	2.9	52.0	4.8	1.7	2.1	40.0
Mixture 4	5.5	13.7	69.5	6.4	2.3	2.7	20.1
Mixture 5	4.8	24.3	60.8	5.6	2.0	2.5	30.1
Mixture 6	4.2	35.0	51.9	4.8	1.7	2.4	40.3
Mixture 7	26.1	1.3	55.6	7.4	0.5	9.0	30.0
Mixture 8	4.1	23.7	55.1	7.6	0.5	9.1	30.3
Mixture 9	15.1	12.2	55.7	8.0	0.5	8.5	29.6
Mixture 10	36.4	1.0	48.3	6.7	0.5	7.2	39.3
Mixture 11	3.7	33.0	48.3	7.1	0.5	7.4	38.9
Mixture 12	17.5	1.9	26.4	52.3	0.8	1.1	19.9
Mixture 13	28.6	1.7	22.9	45.3	0.7	0.8	30.6
Mixture 14	39.7	1.4	19.3	38.2	0.6	0.8	41.4
Mixture 15	18.5	2.0	54.8	15.8	6.4	2.5	21.4
Mixture 16	29.7	1.7	47.2	13.5	5.5	2.4	32.3
Mixture 17	40.5	1.4	39.8	11.4	4.6	2.2	42.8

[a]ME1: high oleic soybean methyl esters. ME2: corn methyl esters. ME3: canola methyl esters. ME3 Sat: fractionated canola methyl esters containing majority of the saturates. ME3 Unsat: fractionated canola methyl esters with a majority of the saturates removed. Mixture 1: ME1 + C16:0 for a total of 20% saturates. Mixture 2: ME1 + C16:0 for a total of 30% saturates. Mixture 3: ME1 + C16:0 for a total of 40% saturates. Mixture 4: ME1 + C18:0 for a total of 20% Saturates. Mixture 5: ME1 + C18:0 for a total of 30% saturates. Mixture 6: ME1 + C18:0 for a total of 40% saturates. Mixture 7: C16:0 20% + C18:1 80%. Mixture 8: C18:0 20% + C18:1 80%. Mixture 9: C16:0 10% + C18:0 10% + C18:1 80%. Mixture 10: C16:0 30% + C18:1 70%. Mixture 11: C18:0 30% + C18:1 70%. Mixture 12: ME2 + C16:0 for a total of 20% saturates. Mixture 13: ME2 + C16:0 for a total of 30% saturates. Mixture 14: ME2 + C16:0 for a total of 40% saturates. Mixture 15: ME3 + C16:0 for a total of 20% saturates. Mixture 16: ME3 + C16:0 for a total of 30% saturates. Mixture 17: ME3 + C16:0 for a total of 40% saturates.
[b]Other includes methyl esters of either C16:1, C20:0, C22:0, C22:1.
[c]Total Saturates includes any of C16:0, C18:0, C20:0 methyl esters.

TESTING PROCEDURE

Low temperature calorimetry studies were performed to understand the thermal behavior of PCMs. The absorption of water and PCM into LWA was also studied.

Low temperature differential scanning calorimetry

To determine the thermal properties of the potential PCM samples, a TA Q2000 low temperature differential scanning calorimetry (LT-DSC) instrument was used. The heat flow and temperature associated with phase transitions in materials was obtained. Tzero aluminum pans with hermetic lids were used to contain the samples. The initial temperature of the test was set to equilibrate at 40°C. After the initial temperature became stable, the LT-DSC cell was cooled to -80 °C at a cooling rate of 5°C/min. The temperature of the specimen was then increased to 40°C at a rate of 5°C/min. The mass of sample was 11 mg ± 2 mg.

Absorption of water into LWA

The absorption capacity of water for the LWA was tested using a vacuum procedure [19]. To saturate the LWA specimens, the LWA was placed in a desiccator and were evacuated to a pressure of 10 mm Hg ± 5 mm Hg for 3 hours. After evacuation and while still under vacuum, de-aerated water (de-aerated by vacuuming the solution for 15 min) was introduced into the desiccator to cover the specimens for 1 hour. LWAs were maintained in a condition where they were submerged below water for 18 hours. The water was removed from the surface of aggregate by using a centrifuge [20]. The surface saturated dry (SSD) samples were then placed in a 105 °C for a day and the water absorption was calculated. The mass percent absorbed was calculated using Equation 1.

Equation 1.
Mass Percent Absorbed.

$$Mass \% = \frac{LWA_{SSD} - LWA_{Dry}}{LWA_{Dry}} \times 100$$

Absorption of PCM into LWA

The absorption of PCM into LWA was evaluated using two different conditions: ambient and vacuum pressure. Under ambient conditions, the LWA samples were weighed into flasks and covered with methyl esters (ME2). Methyl esters were allowed to penetrate the pores for 24 hours before being toweled dried (SSD condition) and weighted. The mass percent absorbed was calculated using Equation 1.

For vacuum pressure absorption, LWA was weighed and placed into a flask. The flask was exposed to vacuum pressure of approximately 80.5 kPa for 45 minutes. Methyl esters (ME1) were then introduced into the flask to completely submerge the aggregate. Operation of the vacuum was stopped and air was allowed back into the flask to drive the methyl esters into the pores of the aggregate for 30 minutes [21]. The aggregate with methyl esters were towel dried (SSD condition) and weighed to calculate the absorbed percentage, using equation 1. The set up for the vacuum absorption experiment can be seen in Figure 5.
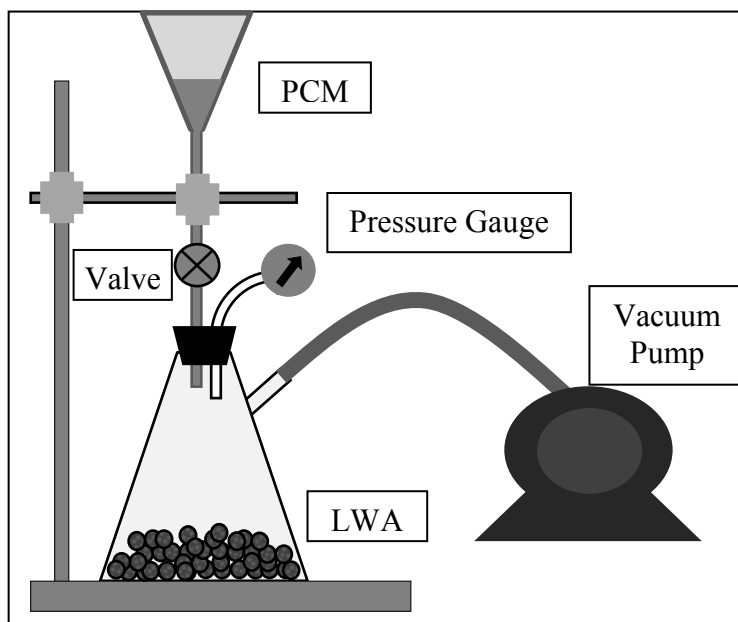
Figure 5. Vacuum absorption experiment.

RESULTS AND DISCUSSION

Thermal response of PCMs

Figure 6 contains a typical DSC result of a test performed on a methyl ester mixture. The most important feature of methyl esters is the type of bonds and amount of carbons in hydrocarbon chain. The mixtures used in testing contained a majority of C16:0 (methyl stearate), C18:0 (methyl palmitate), C18:1 (methyl oleate), C18:2 (methyl linoleate), and C18:3 (methyl linolenate) and approximately 3% of other methyl esters.
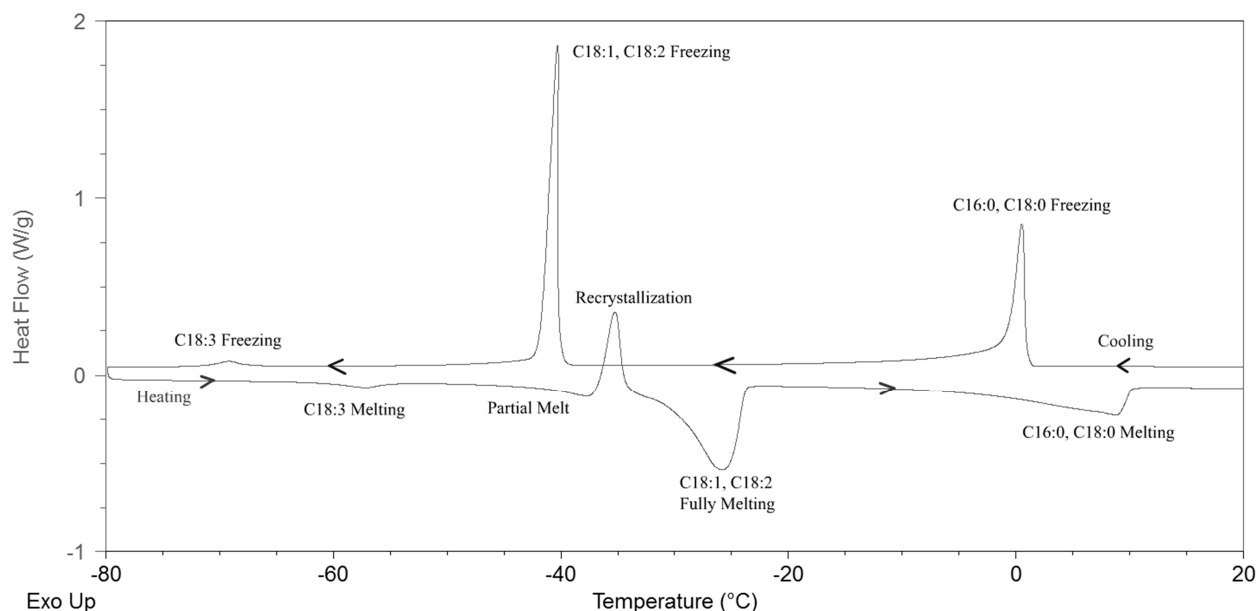
Figure 6. Typical DSC response during cooling and heating.

The first exothermic peak that occurs in Figure 6 indicates the freezing of saturated methyl esters (C16:0 and/or C18:0), and the latter exothermic peaks are associated with the freezing of increasingly unsaturated methyl esters (i.e., more double bonds). These unsaturated methyl esters are the first to melt during heating cycle. Re-crystallization events occur during the heating cycle, illustrating the complex nature of TAGs and their derivatives. This behavior is a consequence of polymorphism, the ability to crystallize in multiple crystallographic patterns [22]. The melting of one type of methyl ester triggers the re-crystallization of another type, which in turn causes both types to melt [23]. Because the melting temperature of the saturated methyl esters is much higher than their freezing temperature, they can demonstrate supercooling. A liquid may freeze at a temperature below its melting point. This phenomenon is known as super-cooling or under-cooling. The supercooling occurs because of two possible reasons: first due to nucleation difficulties, and second the unsaturated methyl esters are preventing the saturated methyl esters from freezing in a solute/solvent interaction, governed by the freezing point depression theory [24]. Although the enthalpy of the unsaturated methyl esters during freezing does not appear to be useful for melting ice (since its freezing point is significantly lower than melting point for ice), their presence is necessary to make the saturated methyl esters behave in a desirable manner. The heating curves may be a better representation of thermal behavior of PCM since no supercooling appears in heating part of DSC results.

Figure 7a. shows the melting curves for high oleic soybean methyl esters, corn methyl esters, canola methyl esters, fractionated canola methyl with a majority of the saturated methyl esters removed, and fractionated canola methyl esters containing the majority of the saturates. The differences between ME1, ME2, and ME3 are attributed to the composition differences. Both ME1 and ME3 display the first small peak which is comprised of C18:3 melting; ME2 does not display this peak because of the lack of C18:3 in its composition. The temperature for second peak (C18:1 and C18:2 behavior) for ME2 occurs at a significantly lower temperature than both ME1 and ME3 because ME2 contains a greater amount of C18:2 (C18:2 has a lower

crystallization point than C18:1). When comparing the canola methyl ester sample (ME3) to the fractionated canola methyl ester samples (ME3-Sat and ME3-Unsat), the DSC result shows changes in the desired peak (near 0 °C). In ME3-Unsat, the desired peak is no longer present, due to the removal of the saturated methyl esters. In ME3-Sat, the saturated methyl ester peak increases because it contains the majority of the saturated methyl esters that were removed from original sample. This result further emphasizes that saturated methyl esters are needed in the PCMs to have an energy release at the desired temperature range.

Figure 7b. demonstrates that with the same percentage of C16:0 or C18:0 added to C18:1, the enthalpy will be lower and the melting point will be higher with the addition of C18:0 compared to C16:0. The comparison between 20% C16:0 versus C18:0 is seen in Mixture 7 and Mixture 8 and the comparison between 30% C16:0 vs. C18:0 is seen in Mixture 9 and Mixture 10, respectively. Therefore, C16:0 may be chosen as the desired saturated methyl ester used in generating PCMs since the enthalpy needs to be as high as possible to increase the amount of ice melting on concrete pavement. It should be also mentioned that the amount and type of unsaturated methyl esters plays an important role in depressing the saturated methyl ester's freezing temperature.
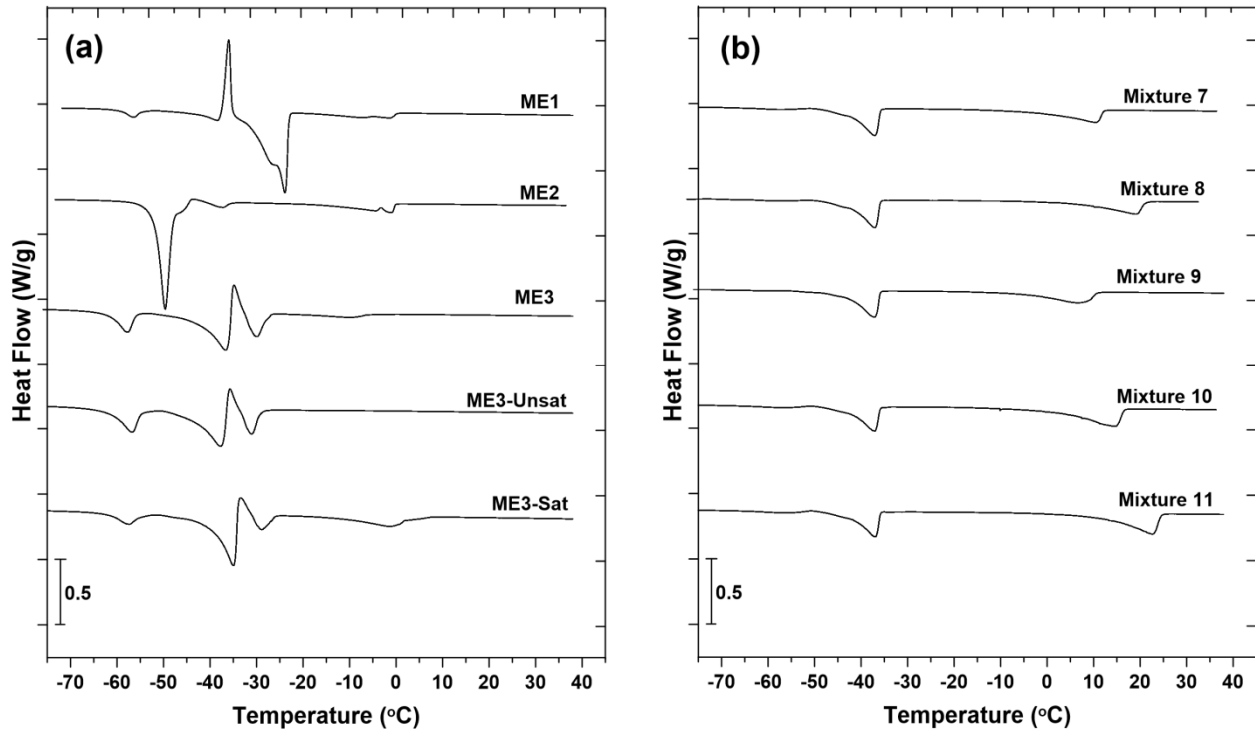

Figure 7. DSC responses during only heating for methyl esters mixtures.

Thermal properties of PCMs

Table 3 contains the thermal properties of the first exothermic peak (associated with freezing the saturated methyl esters), the last endothermic peak (associated with melting the saturates) and the total enthalpy for all the enthalpic releases during the cooling or heating curves. Since the freezing/melting/enthalpy of saturated methyl esters can influence the ice melting efficiency of PCM, the first exothermic peak and the last endothermic peak are reported in this table. The

temperature values are reported at the peak maximum rather than the onset temperature for the individual peaks. The enthalpy of the entire mixture cannot be used as an indication for ice melting because the different chemical species are freezing at their preferred temperature rather than freezing as a whole in a temperature near to ice melting temperature (0 °C). The enthalpy of freezing for saturated methyl esters appears to be related to total saturated methyl ester content. In addition, the composition of the saturated methyl esters content seems to also affect the enthalpy and freezing temperature.

Table 3.
Thermal properties of methyl ester samples.

| Samples | Cooling Curve | | | Heating Curve | | |
| | C16:0, C18:0 Freezing Peak | | Total Curve Enthalpy (J/g) | C16:0, C18:0 Melting Peak | | Total Curve Enthalpy (J/g) |
	Temp. (°C)	Enthalpy (J/g)		Temp. (°C)	Enthalpy (J/g)	
ME1	-5.87°	(15.47)	(115.00)	-1.46°	(12.60)	(115.00)
ME2	-9.53°	(19.25)	(113.50)	1.01°	(19.84)	(111.10)
ME3	-21.50°	(7.66)	(97.32)	-9.88°	(6.82)	(99.15)
ME3 Sat	-11.41°	(26.94)	(110.00)	-1.29°	(22.72)	(97.43)
ME3 Unsat	-	-	(80.41)	-	-	(85.25)
Mixture 1	-3.38°	(29.54)	(124.40)	-2.38°	(28.32)	(114.70)
Mixture 2	0.52°	(46.64)	(127.10)	8.88°	(45.57)	(119.80)
Mixture 3	6.31°	(60.81)	(138.30)	14.51°	(61.41)	(129.50)
Mixture 4	3.43°	(18.57)	(99.58)	12.02°	(16.20)	(87.93)
Mixture 5	11.56°	(32.86)	(111.40)	19.28°	(28.61)	(96.13)
Mixture 6	16.57°	(48.82)	(113.00)	23.69°	(46.03)	(96.88)
Mixture 7	0.24°	(30.31)	(72.79)	10.44°	(28.88)	(63.01)
Mixture 8	10.44°	(29.70)	(67.57)	18.99°	(29.26)	(58.17)
Mixture 9	1.92°	(26.15)	(69.19)	6.63°	(24.56)	(62.14)
Mixture 10	7.16°	(45.23)	(77.37)	14.71°	(42.54)	(73.93)
Mixture 11	15.08°	(45.95)	(90.92)	22.72°	(42.82)	(76.15)
Mixture 12	-5.23°	(22.03)	(86.60)	4.57°	(20.22)	(87.82)
Mixture 13	2.53°	(36.62)	(94.46)	11.45°	(34.44)	(89.65)
Mixture 14	8.18°	(53.62)	(112.40)	15.92°	(52.35)	(101.00)
Mixture 15	-4.61°	(22.28)	(84.33)	3.14°	(21.95)	(76.51)
Mixture 16	2.07°	(37.86)	(97.87)	9.18°	(38.99)	(87.40)
Mixture 17	7.82°	(52.25)	(102.00)	15.94°	(50.48)	(77.34)

*ME3 Unsat did not display the saturated methyl ester peak

Absorption of water and PCM into LWA

In Table 4, the water vacuum absorption experiment results which can be used as a control experiment for the total possible absorption is compared with the vacuum and ambient absorption of LWAs into concrete.

Table 4.
Lightweight aggregate absorption of water or PCM under vacuum and ambient conditions.

Sample	Retained Sieve Number	Water Vacuum Absorption (mass %)	PCM Vacuum Absorption (mass %)	PCM Ambient Absorption (mass %)
LWA #1		32%	20%	9%-
Graded LWA #1	#4	-	20%	13%
	#8	35%	27%	16%
	#16	33%	25%	20%
	#30	31%	25%	20%
	#50	29%	24%	16%
	Pan	26%	-	-
LWA #2		23%	23%	11%
Graded LWA #2	#4	-	21%	8%
	#8	29%	22%	10%
	#16	26%	21%	12%
	#30	19%	15%	12%
	#50	17%	8%	7%
	Pan	13%	-	-

The vacuum pressure conditions for methyl ester absorption can be used as the control for the maximum absorption of methyl esters (Figure 8). Comparing these results to the water absorption experiment (Table 4), the data shows that the methyl esters under vacuum conditions are not reaching the maximum possible mass percent absorption of the water. These differences might be due to changes in specific gravity, viscosity, and surface tension of the liquid. More research and experimentation is needed to determine the specific factors affecting this slight decrease in the absorption of methyl esters.

Methyl ester absorption under the ambient conditions is also compared with the vacuum pressure conditions in Figure 8. It appears that as the lightweight aggregate size decreases the difference between the amounts absorbed between vacuum and ambient conditions decreases. One possible explanation for this is that the pores in the larger aggregate are bigger and therefore, due to the lack of sufficient capillary suction, more time is needed at ambient conditions for methyl esters to ingress fully into the pores.
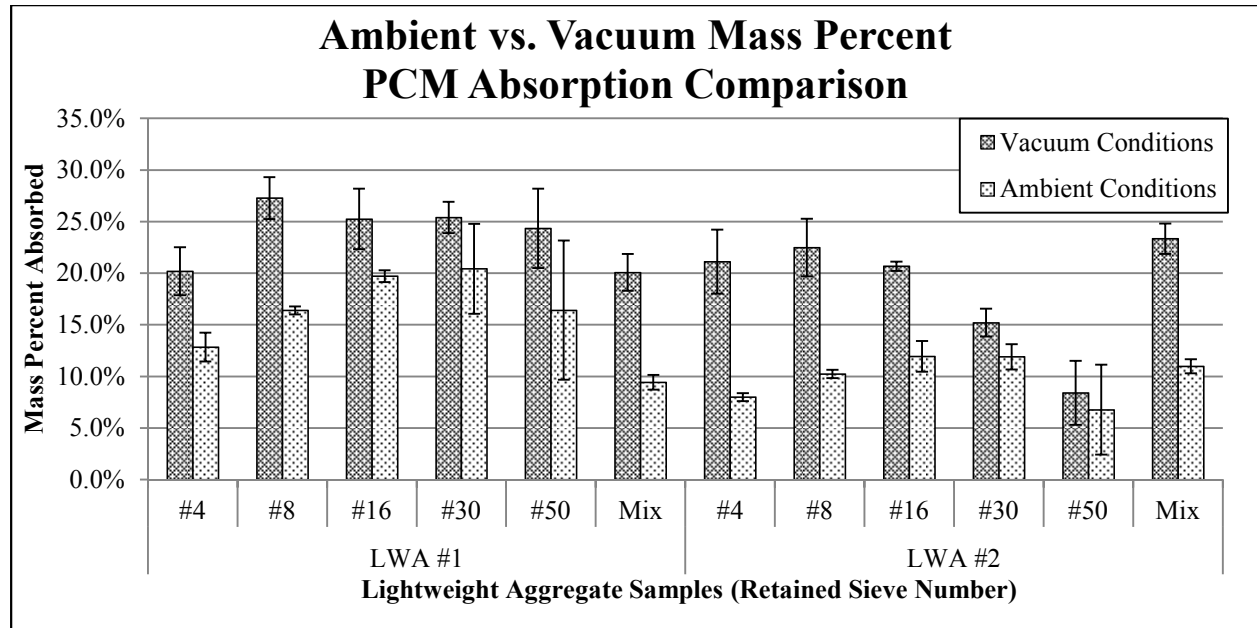
Figure 8. Comparison of vacuum and ambient methyl ester mass percent absorption conditions
(The error bars represent ± one standard deviation between three trials).

CONCLUSION

In this paper, the technology that may be able to incorporate PCMs in concrete pavement by inclusion of the PCM in LWA is discussed. Several organic PCMs are evaluated for their potential use in concrete pavement and their thermal properties are determined. In addition, the absorption of PCM into LWA was investigated. Based on the results obtained in this work, following conclusions can be drawn:

- A change in the concentration and the type of saturated methyl esters (C16:0 and C18:0) alters the thermal properties of a methyl ester PCM samples. Increasing the methyl palmitate content (C16:0) results in a change toward the desired thermal properties required for concrete pavement application and ice melting.
- A change in the type of unsaturated methyl esters influences the freezing temperature of the saturated methyl esters. It seems that the use of unsaturated methyl esters with multiple double bonds (C18:2 & C18:3) tends to suppress the freezing temperature of the saturated methyl esters more than methyl esters with a single double bond (C18:1).
- It seems that there is a slight reduction in PCM ingress into the LWA. This reduction is considerable when the LWA is saturated in an ambient condition.
- Only a small portion of entire enthalpy for the methyl ester PCM samples is released in the temperature range required for ice melting on concrete pavement.

As a part of the ongoing project, more research is being performed to investigate the thermal behavior of other PCMs such as paraffin oil and triacylglycerides. As a first step of the project, it is very important to evaluate thermal properties of PCMs and ways that can maximize PCM

incorporation in concrete. The results discussed in this paper will be used and compared to the future studies; then PCMs possessing desired properties for concrete pavement application will be proposed. The proposed PCMs will then be used to make concrete samples by means of optimized LWAs; and thermal behaviors of concrete samples will be evaluated. Constructability of PCM concrete pavement will be also evaluated by making large concrete slabs. These slabs will be exposed to temperature cycling to study the efficiency of PCM concrete pavement.

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